Overview: COMET, MEG, Mu3e

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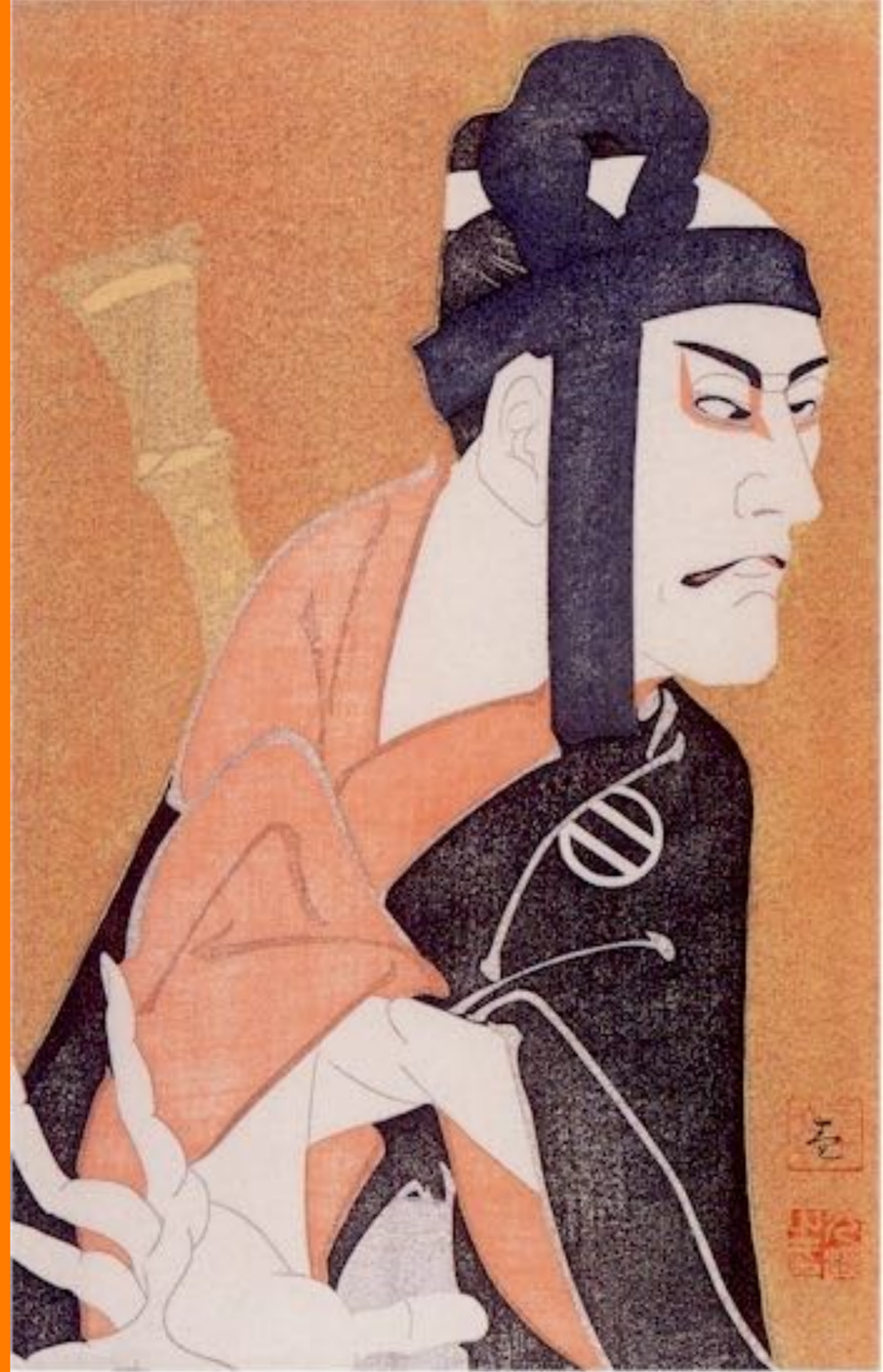
P5 Town Hall Meeting
Fermilab

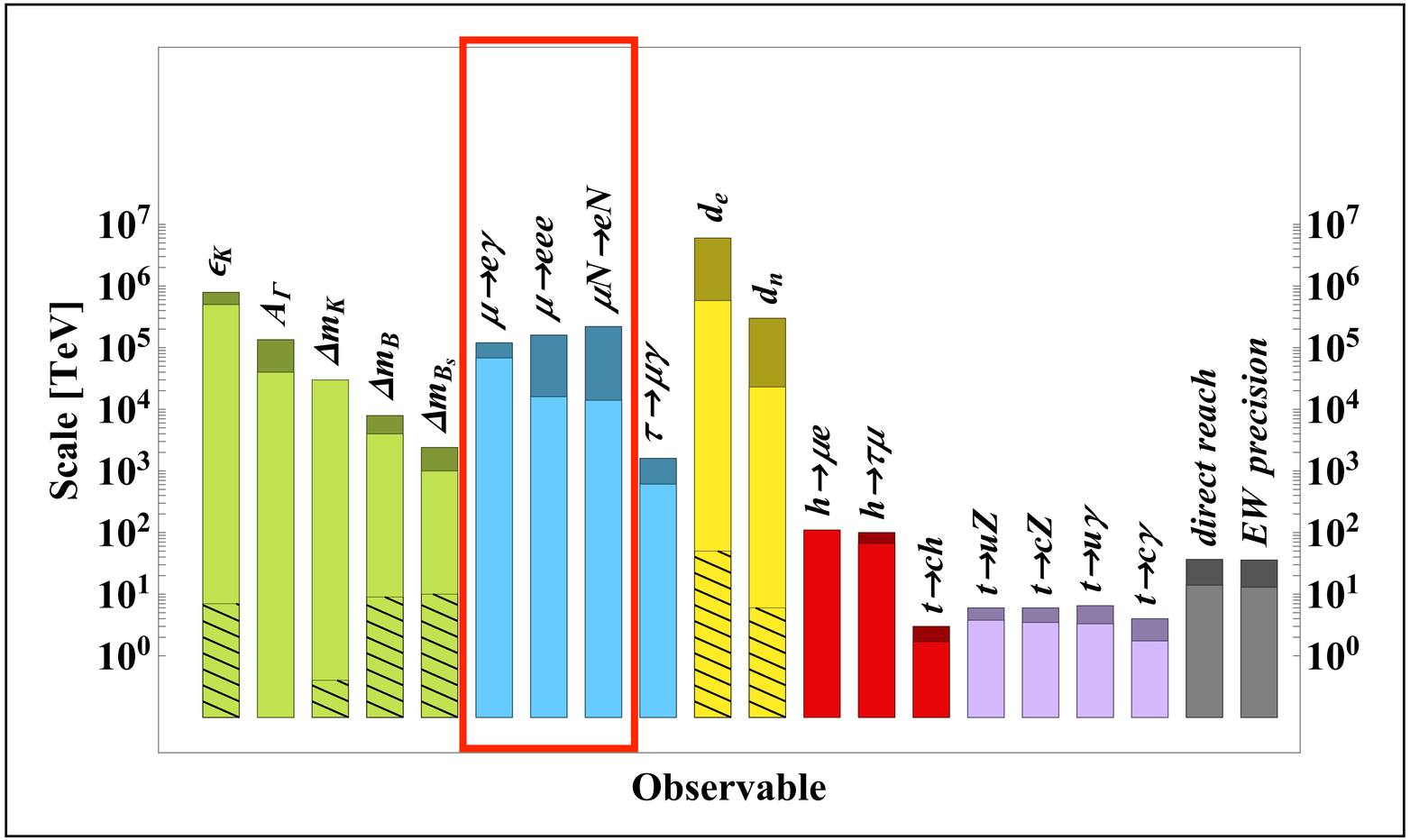
Outline

- Why Muon Charged Lepton Flavor Violation (CLFV) ?
- MEG II @ PSI : $\mu^+ \rightarrow e^+\gamma$
- Mu3e @PSI : $\mu^+ \rightarrow e^+e^+e^-$
- COMET @ J-PARC : $\mu^- \rightarrow e^-$ Conversion
- Summary

Why Muon CLFV ?



New Physics Scales for CLFV



light colour: present
dark colour: future prospect

EPPSU2019 Physics Briefing Book

Present CLFV physics scales

Energy scale $\Lambda = \mathcal{O}(10^3 - 10^4)$ TeV

Future Prospect

x10 in energy scale

SM forbidden rate $\propto \frac{c^2}{\Lambda^4}$

x10000 in experimental sensitivity

CLFV probes very high energy scale of new physics.

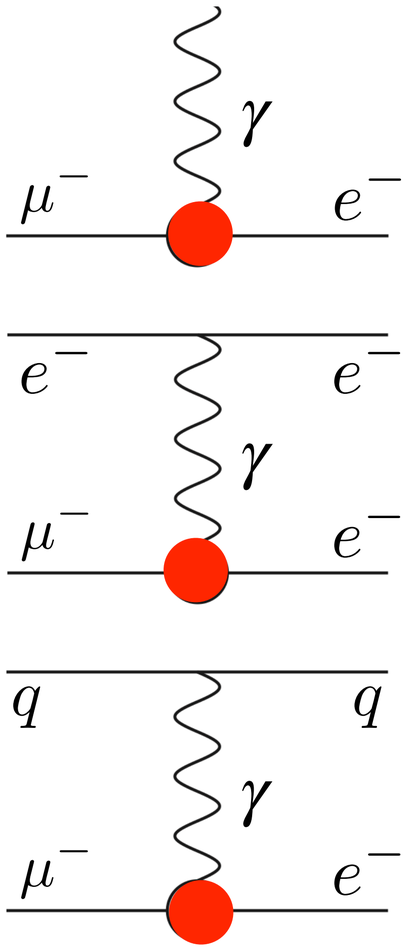
$\mu \rightarrow e$ CLFV Golden Processes

$\mu^+ \rightarrow e^+\gamma$

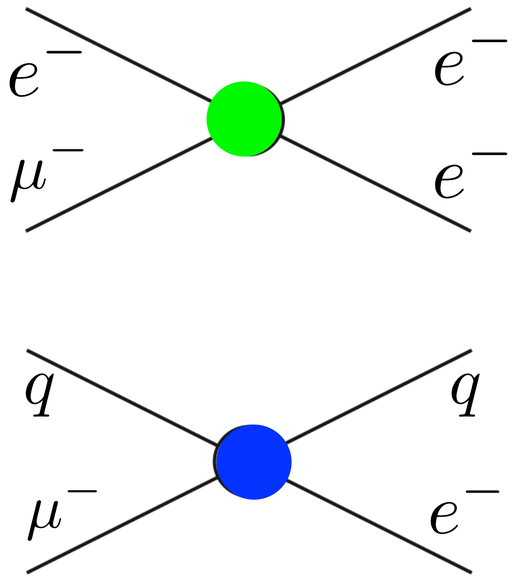
$\mu^+ \rightarrow e^+e^+e^-$

$\mu^-N \rightarrow e^-N$

dipole interaction



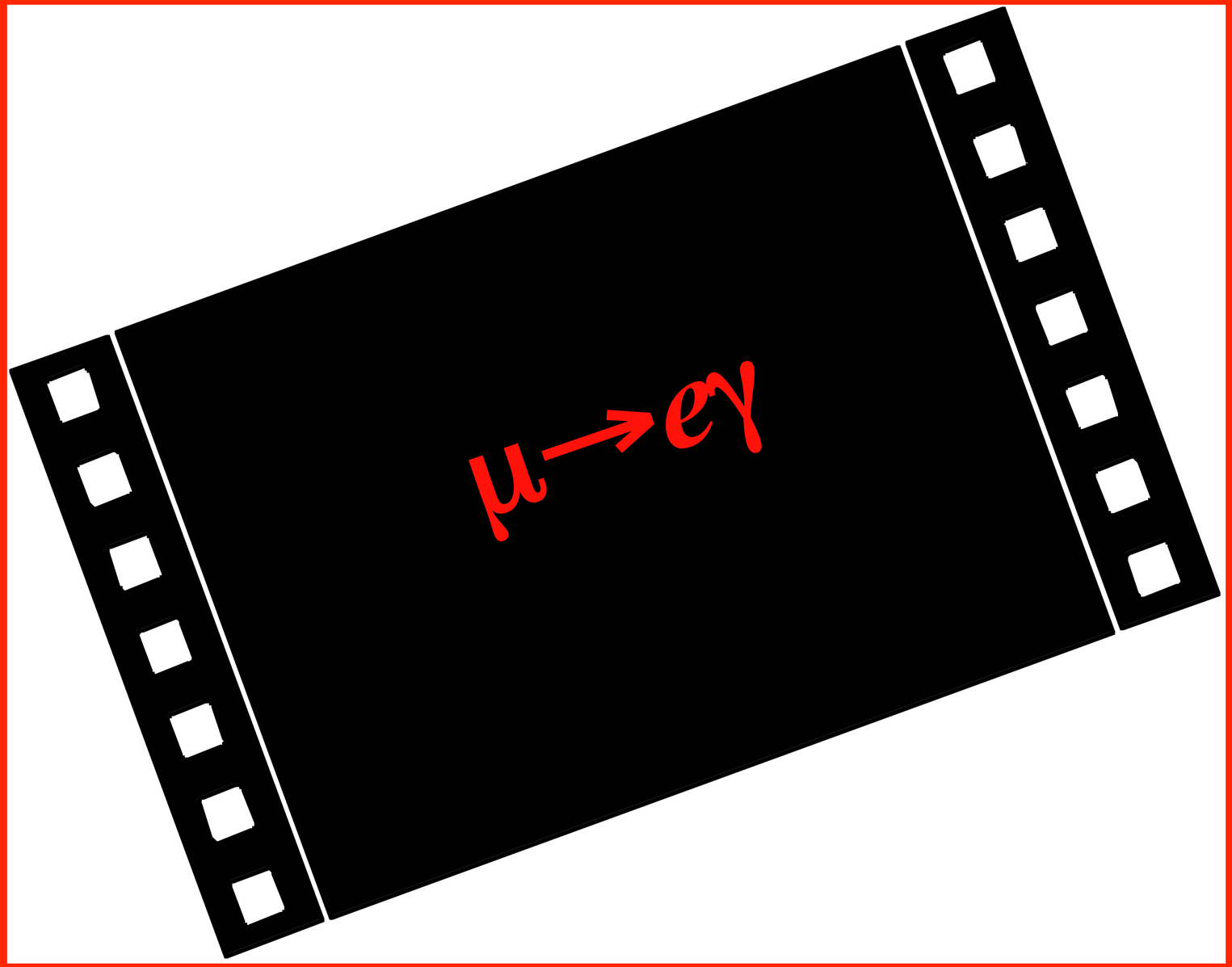
contact interaction



Effective Field Theory (EFT)

- dipole operators (left and right)
- six contact operators (scalar and vector)
- scalar, vector (spin independent)
- axial vector, tensor (spin dependent)

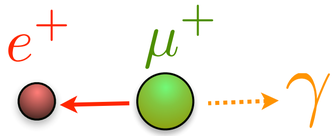
MEG II, Mu3e and COMET

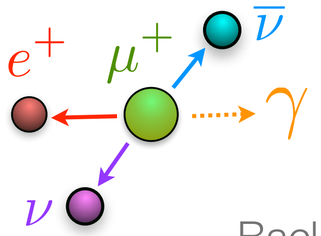

$\mu \to e\gamma$

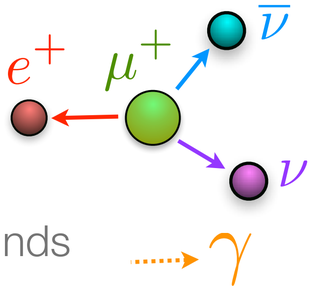
MEG II : $\mu^+ \to e^+\gamma$

- Event Signature (μ^+ decay at rest)
  - $E_e = E_\gamma = m_\mu/2$ (=52.8 MeV)
  - angle $\theta_{e\gamma}$=180 degrees
  - time coincidence $\Delta t_{e\gamma}$
- Backgrounds
  - physics background, $\mu^+ \to e^+\nu\bar{\nu}\gamma$
  - accidental background
    - e^+ in $\mu^+ \to e^+\nu\bar{\nu}$ and
    - γ in $\mu^+ \to e^+\nu\bar{\nu}\gamma$ or AIF
- Current limit
  - MEG experiment at PSI
  - $B(\mu^+ \to e^+\gamma) < 4.2 \times 10^{-13}$

Signature







Backgrounds

New electronics: Wavedream

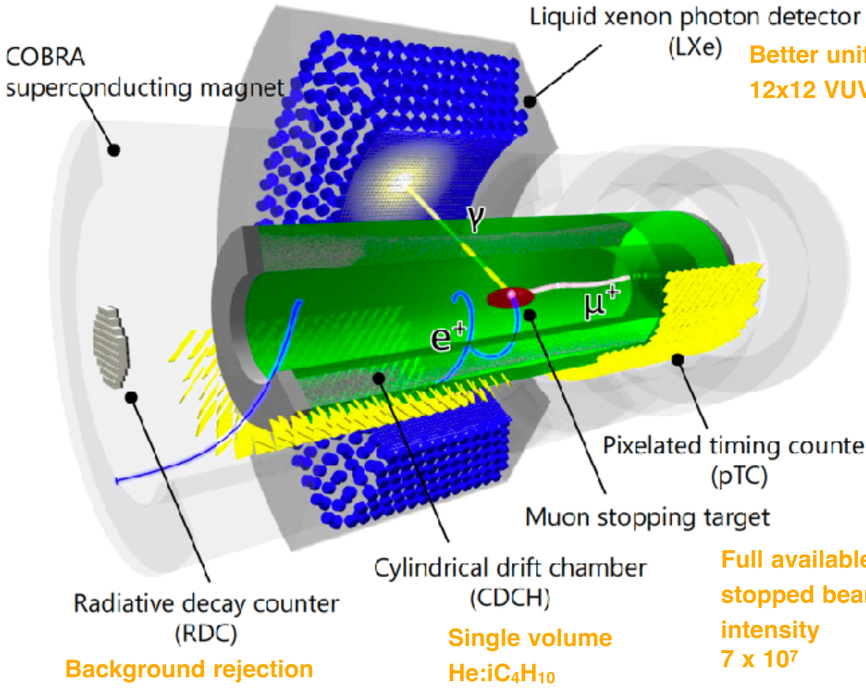
~9000 channels at 5GSPS

x2 Resolution everywhere

Updated and new Calibration methods

Quasi mono-chromatic positron beam

MEG II

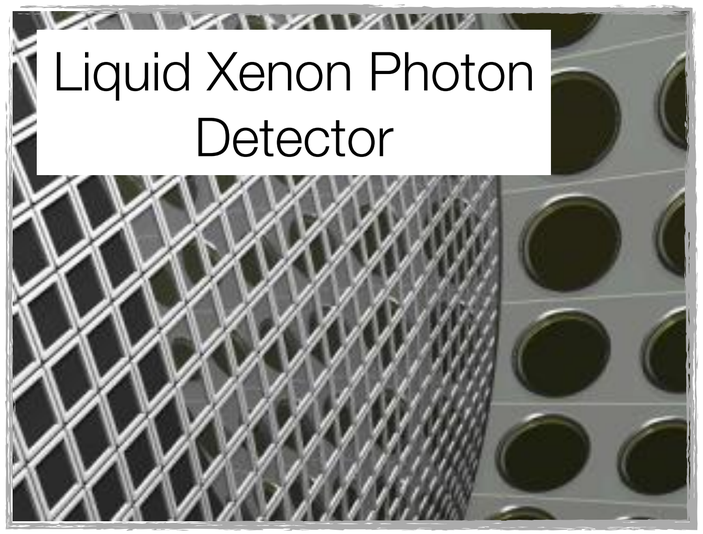


MEG II :$B(\mu^+ \to e^+\gamma) < 6 \times 10^{-14}$

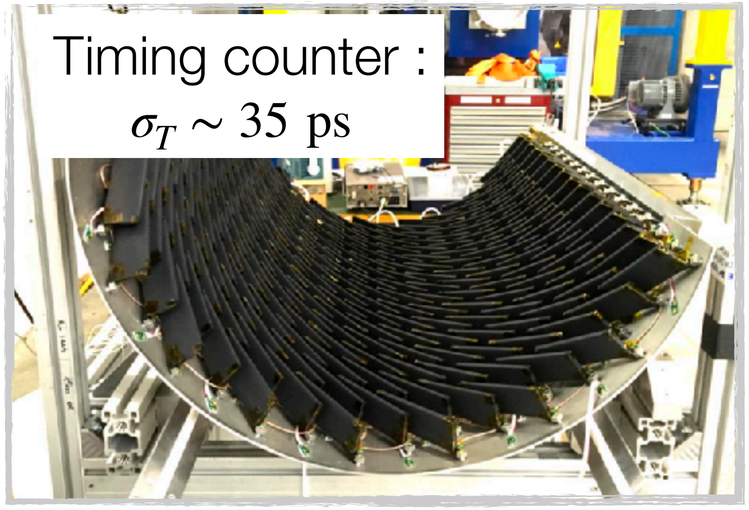
- x2 muon beam intensity
- x2 all detector resolution
- x2 efficiency

MEG II Detector Upgrade

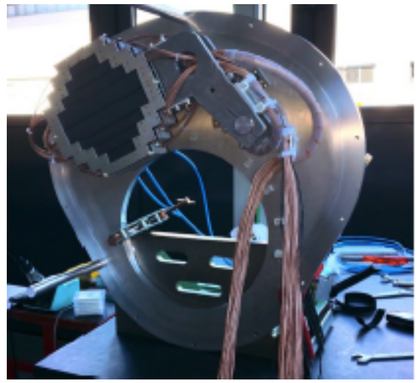
Liquid Xenon Photon Detector



Timing counter :
$\sigma_T \sim 35$ ps

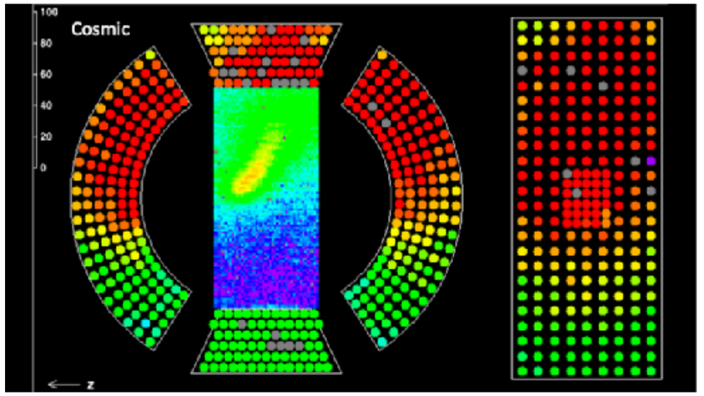


RDC detector

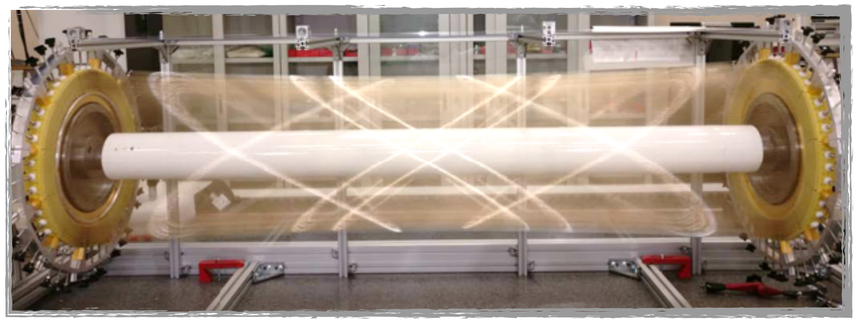


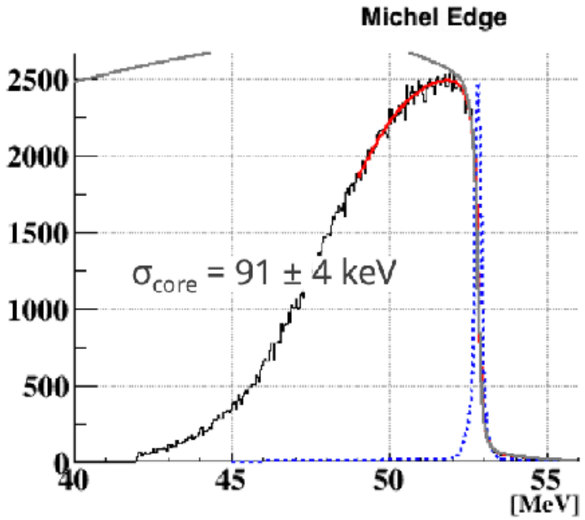
New DAQ/trigger system

Drift chamber



Cylindrical drift chamber

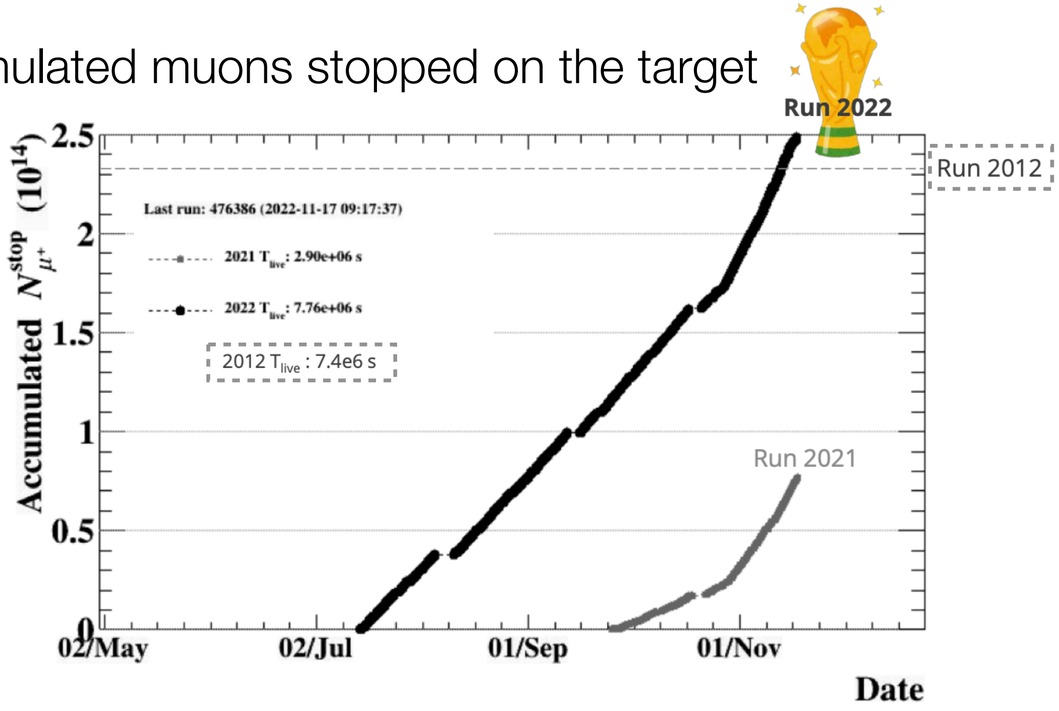




MEG II physics run 2022

- MEG II Physics Run 2022
  - the longest run so far
  - x3 of the MEG II 2021 run
  - > the MEG longest run in 2012

accumulated muons stopped on the target

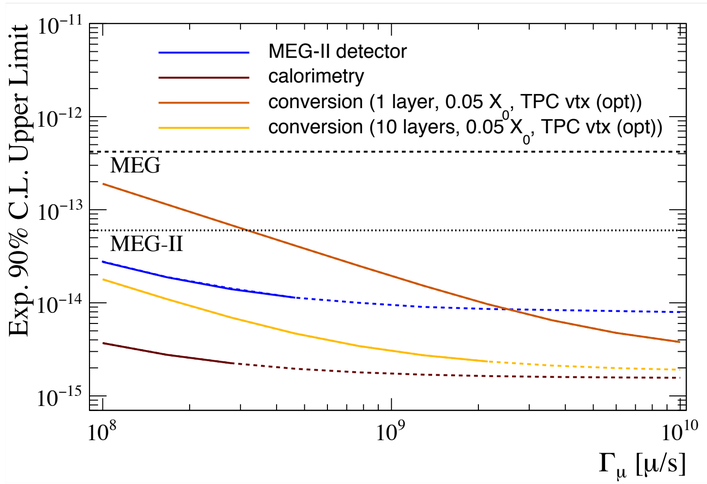


G. Cavoto, A. Papa, F. Renga, E. Ripiccini, C. Voena, Eur. Phys. J. C (2018) 78:37

- Exotic Particle Searches with MEG II
  - $\mu^+ \to e^+ X; X \to \gamma\gamma$
  - $\mu^+ \to e^+ a$
  - $\mu^+ \to e^+ a\gamma$
  - The X17 new boson (w/o a muon beam)

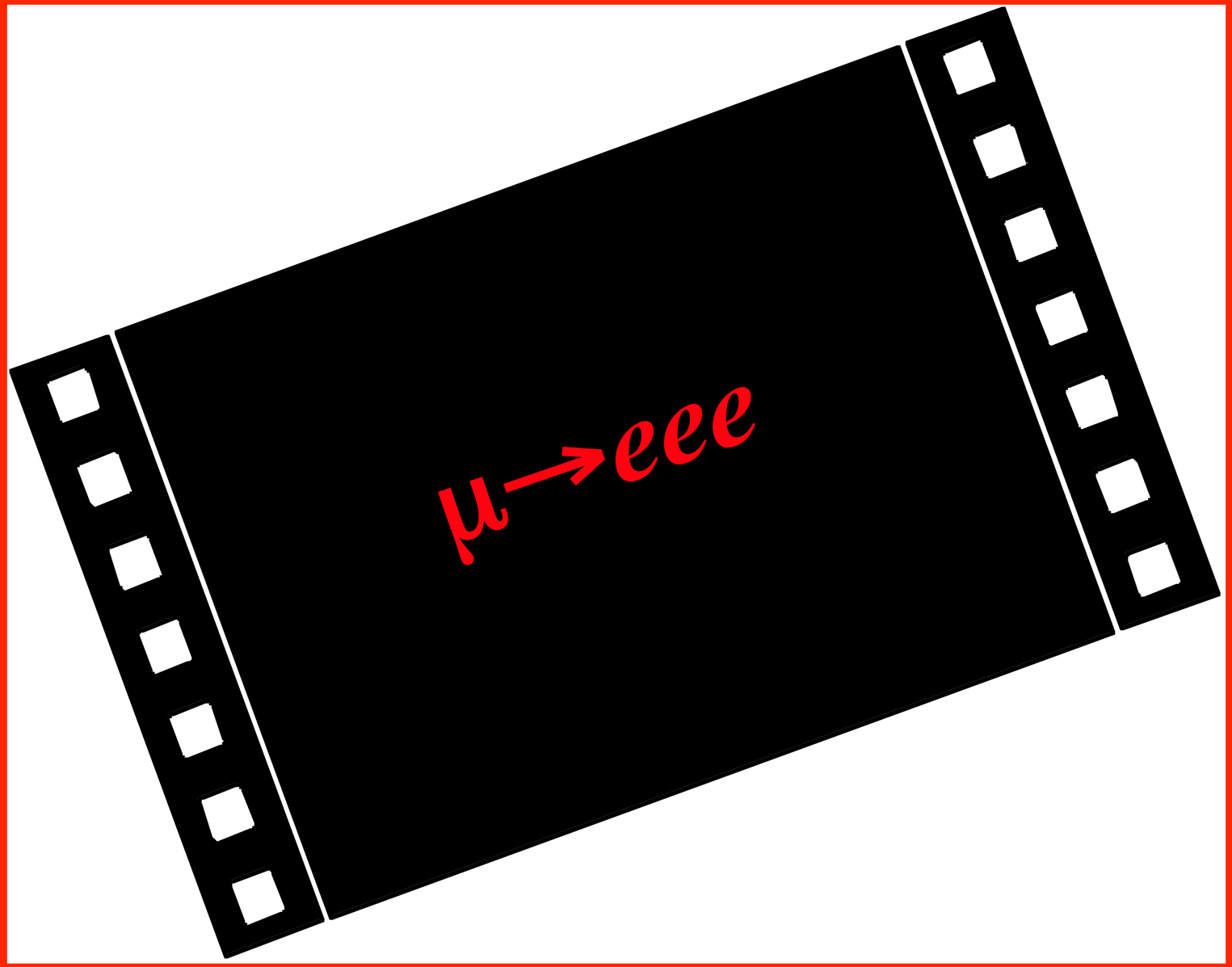
A. Baldini et al. (MEG Collaboration), Eur. Phys. J. C80 (2020) 858

- Beyond MEG II
  - O(10^{10}) muons
  - photon detection
    - conversion
    - calorimeter



Timeline

- Physics runs in 2021,2022,2023 - 2025,(2026)
- PSI HIPA accelerator shutdown for the HiMB installation in 2027-2028

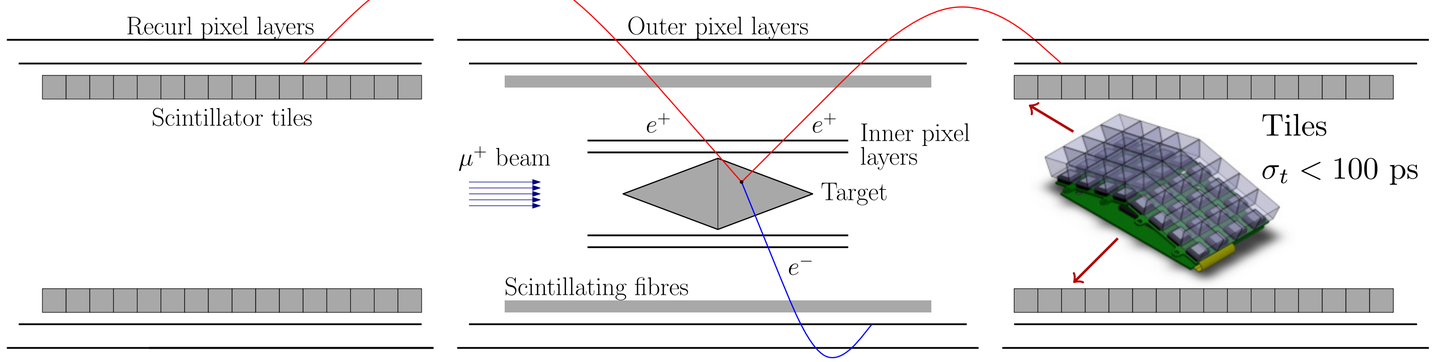

$\mu \rightarrow eee$

$\mu^+ \to e^+e^+e^-$; Mu3e at PSI

- Event Signature (μ^+ decay at rest)
  - $\sum E_e = m_\mu$ and $\sum \vec{p}_e = 0$
  - common vertex and time coincidence
- Backgrounds
  - Physics backgrounds, $\mu^+ \to e^+\nu_e\bar{\nu}_\mu e^+e^-$
  - Accidental backgrounds from Michel decays + Bhabha scattering
- Current limits (from SINDRUM at PSI),
  - $B(\mu \to eee) < 1.0 \times 10^{-12}$ (90% C.L.)
  - 1988
- $\mu \to eee$ Spectrum to be detected
  - depends on the models
  - low momentum threshold, important

Mu3e Phase I

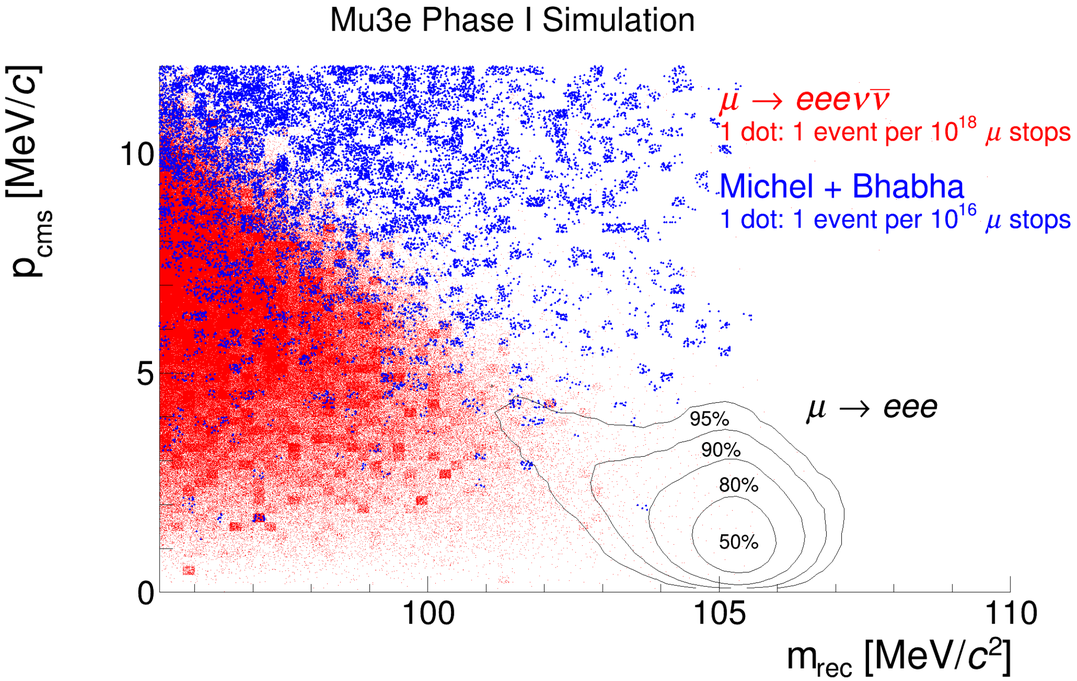
$\mathcal{O}(10^{-15})$ with 10^8 μ/s (πE5)



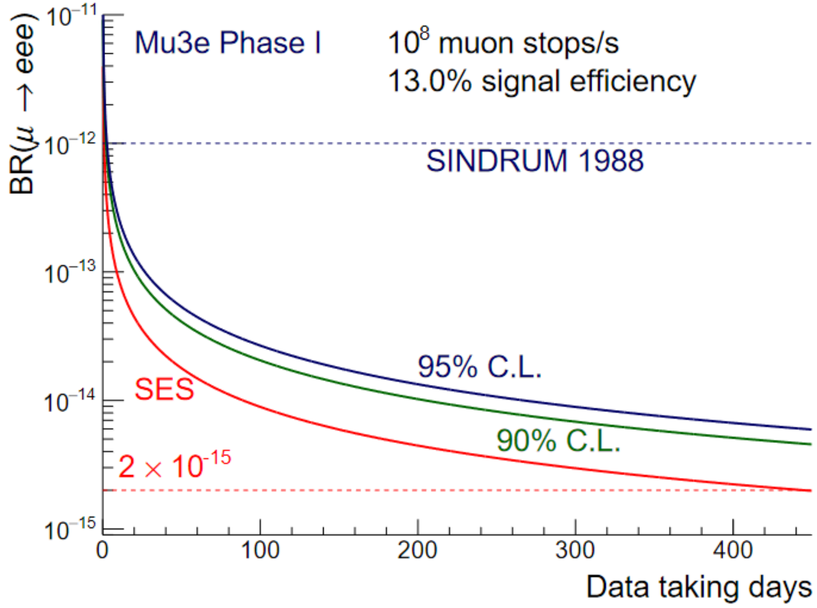
- Ultra thin pixel detector (0.01X_0 per layer)
  - High-Voltage Monolithic Active Pixel Sensors
- Fiber timing detector (250 ps)
- Scintillator tile timing detector (50 ps)
- 1 T superconducting solenoid

Mu3e Phase I Sensitivity

Performance (simulation)



Sensitivity

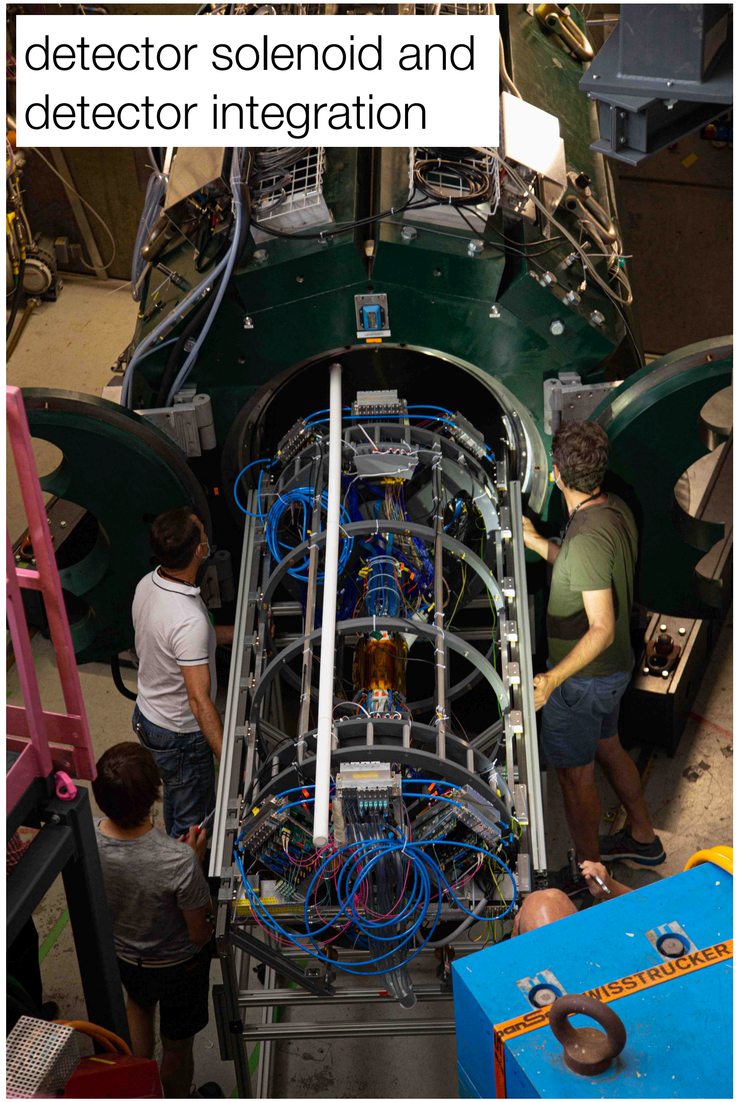


- Exotic searches at Mu3e
  - $\mu^+ \to e^+ a$
  - resonance search $\mu^+ \to e^+ \nu\bar{\nu} a; a \to e^+ e^-$

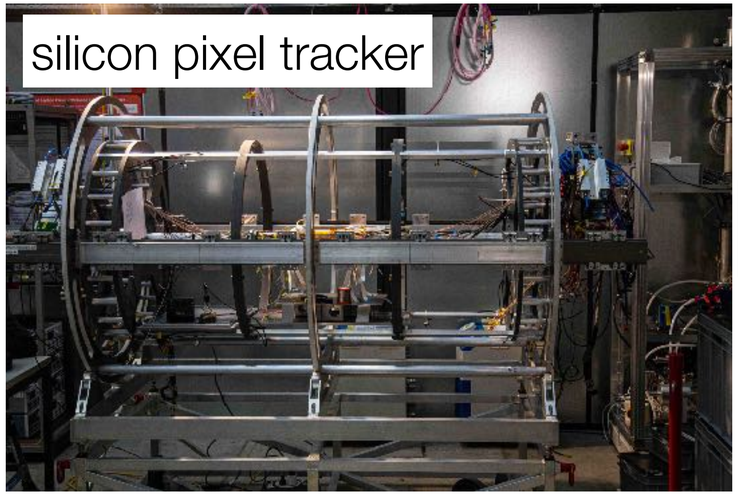
arXiv:1812.00741

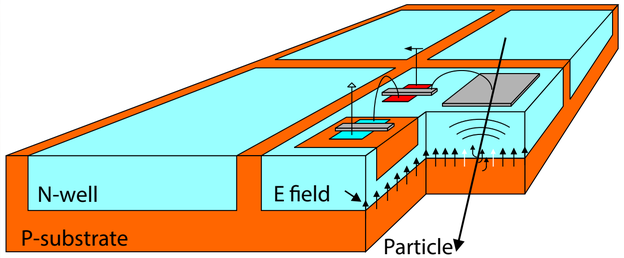
Mu3e Preparation Status

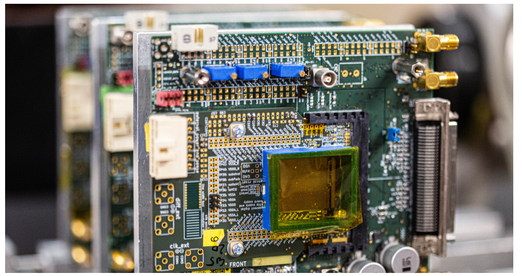
detector solenoid and detector integration



silicon pixel tracker

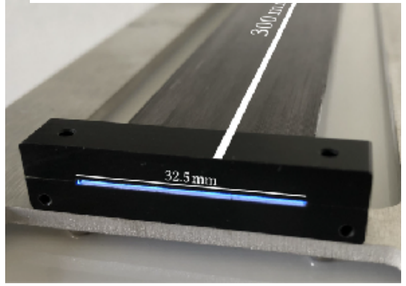






silicon pixel board (50 µm)

SciFi timing counter

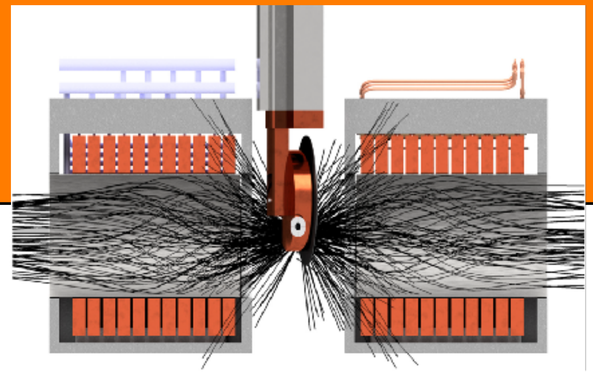


scin. tile counter

Timeline

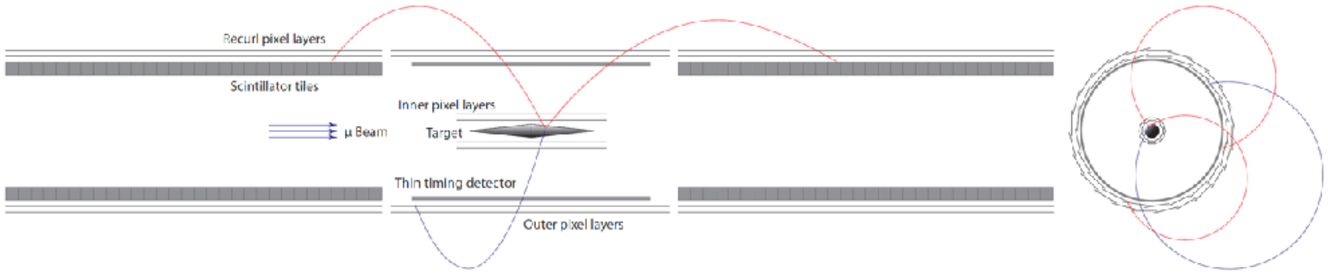
- Integration run in 2021
- Cosmic run in 2022
- Phase I commissioning in 2024
- Phase I physics run in late 2024
- HiMB installation in 2027-2028

Mu3e Phase II



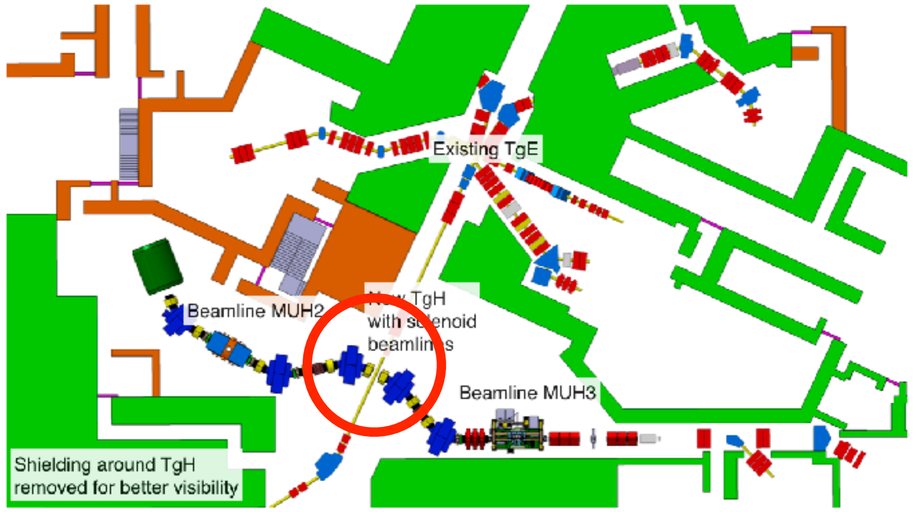
Mu3e Phase II

- Ultimate sensitivity goal of BR < $1x10^{-16}$
- Upgraded Mu3e detector
  - elongated recurl pixel station
  - muon target with smaller radius
  - thinner pixel detector
- muon intensity $2x10^{9}$/sec from HiMB
- scheduled after 2029



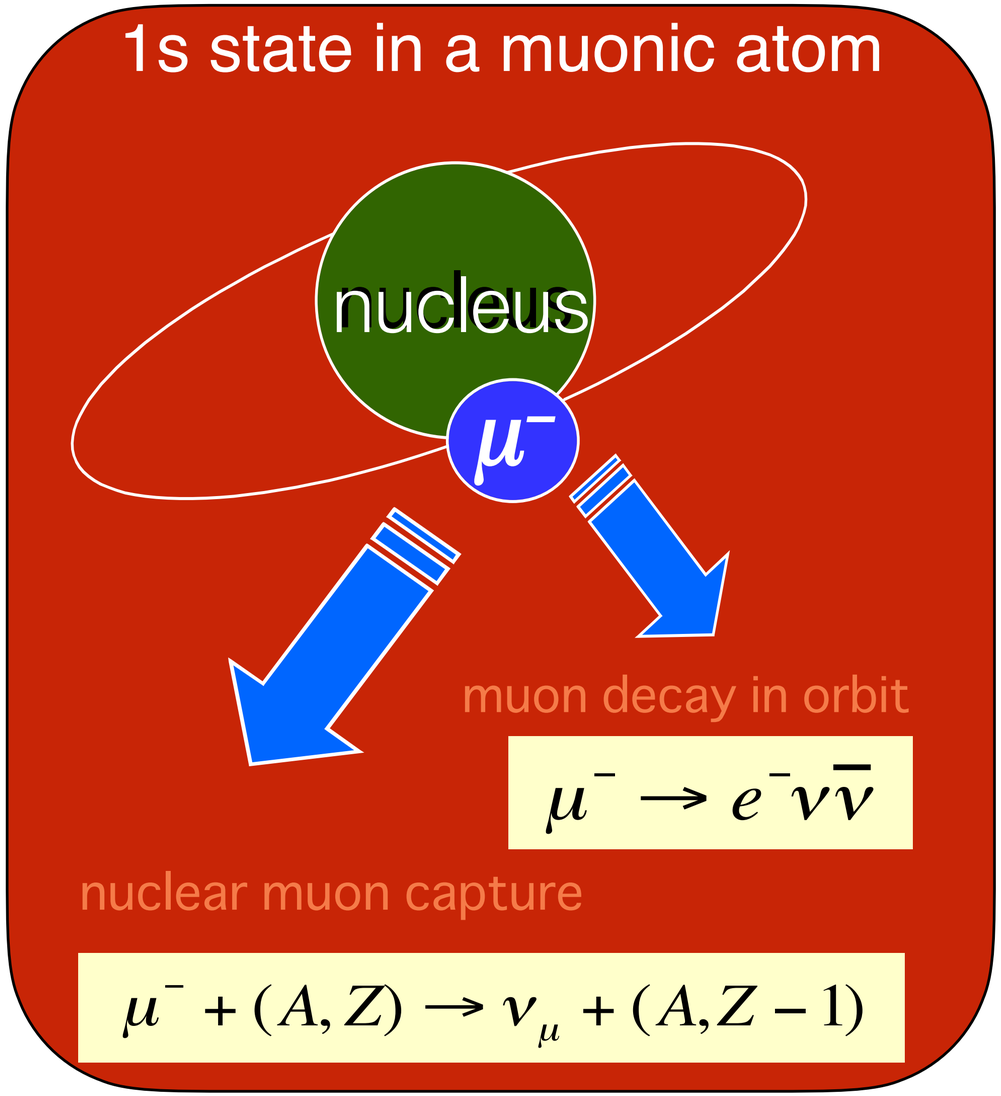
HiMB

- High Intensity Muon Beamline (HiMB) at PSI
- Surface muon (μ^{+}) beam, $O(10^{10})$ /s
- New target and new capturing solenoids
- Installation in 2027-2028
- Planned to be operational in 2029




μ→e conversion
in
a muonic atom

What is $\mu^- \rightarrow e^-$ Conversion ?



$$\mu^- + (A,Z) \rightarrow e^- + (A,Z)$$

coherent process (for transition to ground state)

Event Signature :

a mono-energetic electron

(one particle measurement allows higher muon rates.)

$$E_{\mu e} \approx m_\mu - E_{bound\ \mu} - E_{recoil} \approx 105\ \mathrm{MeV}$$

Backgrounds:

(1) physics backgrounds (muon decay in orbit)

(2) beam-related backgrounds

(3) cosmic rays, false tracking

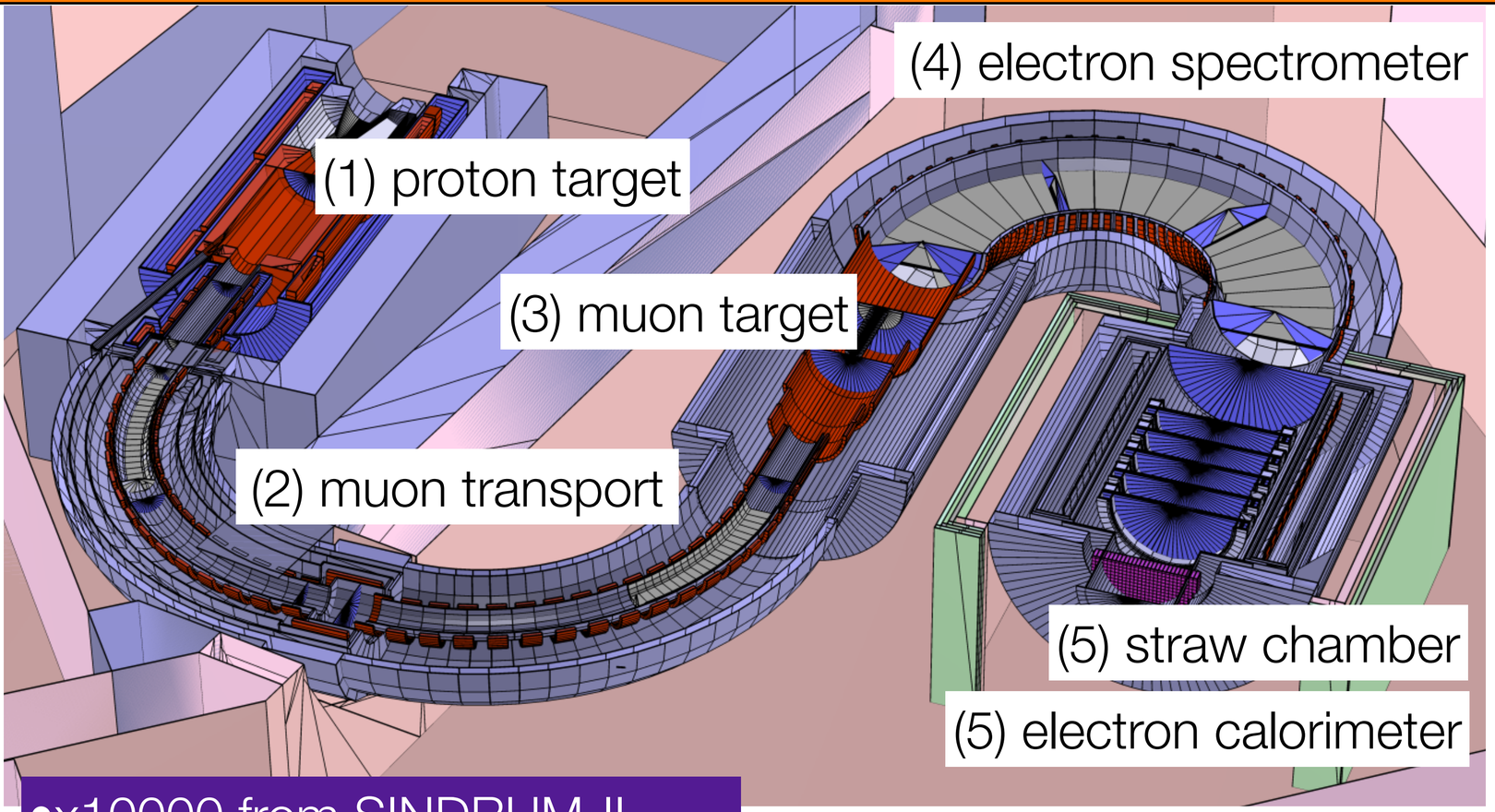
Conversion rate:

$$\mathrm{CR}(\mu^-\mathrm{N} \rightarrow e^-\mathrm{N}) \equiv \frac{\Gamma(\mu^-\mathrm{N} \rightarrow e^-\mathrm{N})}{\Gamma(\mu^-\mathrm{N} \rightarrow \mathrm{all})}$$

nucleus	Z	CR limit
sulfur	16	7×10^{-11}
titanium	22	4.3×10^{-12}
copper	39	1.6×10^{-8}
gold	79	7×10^{-13}
lead	82	4.6×10^{-11}

- COMET= COherent Muon to Electron Transition

COMET at J-PARC



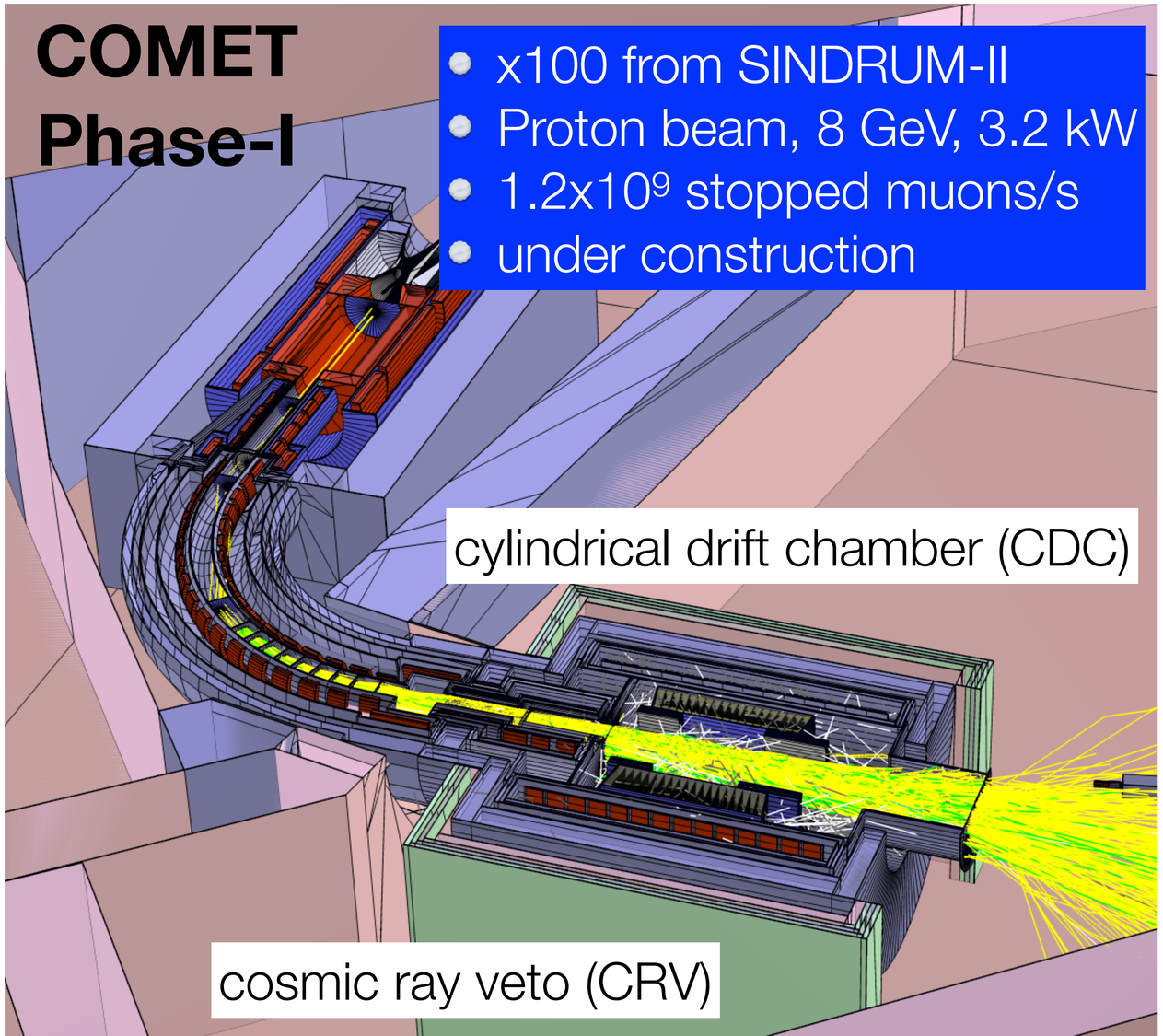
- (1) Proton target under 5 T solenoid field to collect many pions.
- (2) Muon transport : μ-s are momentum and charge selected by curved solenoid.
- (3) Muon target: 17 aluminium disks.
- (4) Electron spectrometer : Electrons of 105 MeV/c are selected by curved solenoid.
- (5) Detector : straw chambers and followed an electron calorimeter.

- x10000 from SINDRUM-II
- 90% CL limit : < 4.6 x10^{-17}
- Total background: 0.32 events
- Running time: 2x10^{7}sec

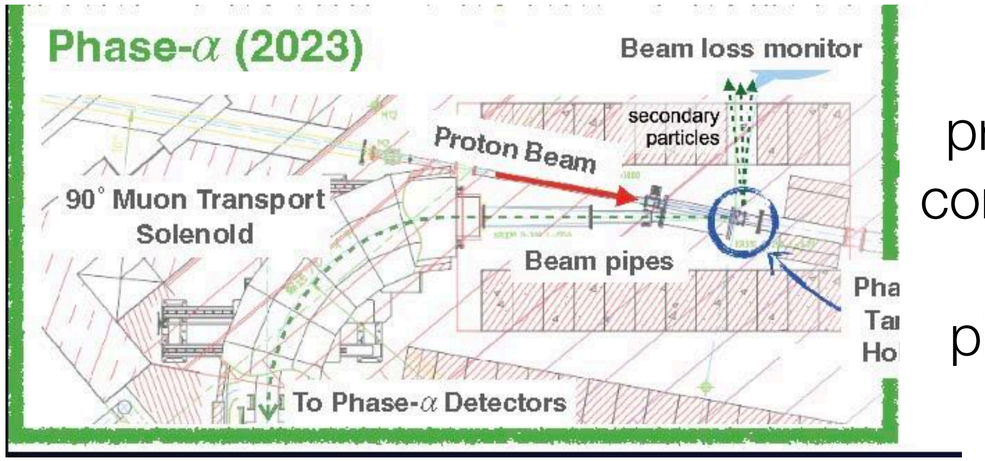
- Proton beam, 8 GeV, 56kW
- O(10^{11}) stopped muons/s

- Other physics:
  - $\mu^- N \rightarrow e^+ N'$ (CLFV and LNV)
  - bound $\mu^- \rightarrow e^- a$

COMET Staged Approach

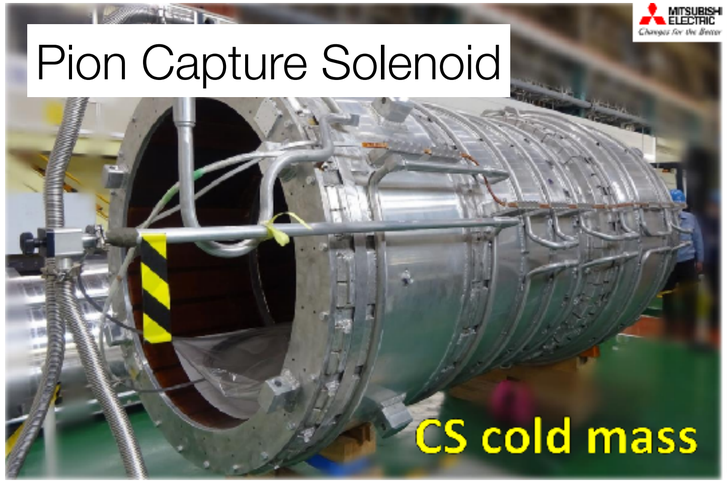


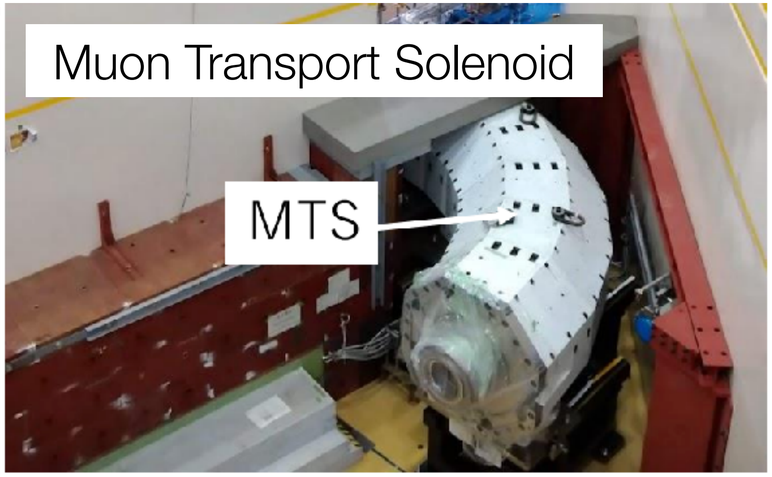
	Phase-I	Phase-II	(Phase-II)+
proton beam	8 GeV, 3.2 kW	8 GeV, 56 kW	8 GeV, 56 kW
proton target	graphite	tungsten	tungsten
transport	90° bend	180° bend	180° bend
muons stop	1.2×10^{9}/s	1×10^{18}	2×10^{11}/s
run time	150 days	200 days	300 days
detector	CyDet	StrECAL	StrECAL
90% CL	$<7\times10^{-15}$	$<4.6\times10^{-17}$	$<7\times10^{-18}$
backgrounds	0.03 events	0.32 events	0.6 events

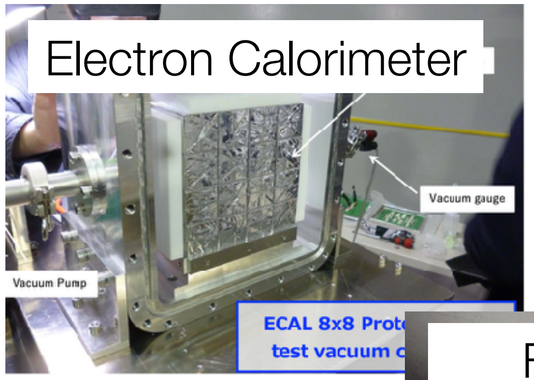


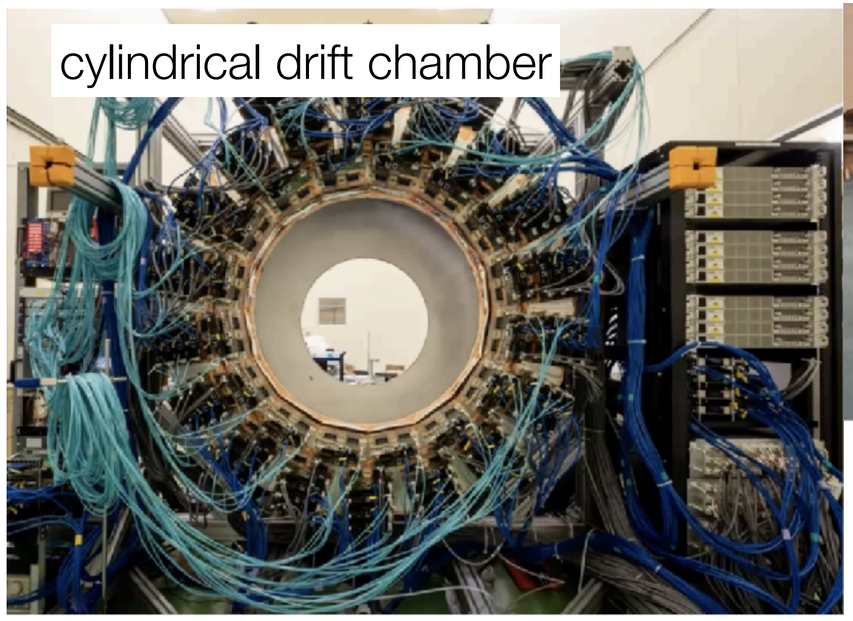
COMET proton beam commissioning w/o pion capture solenoid

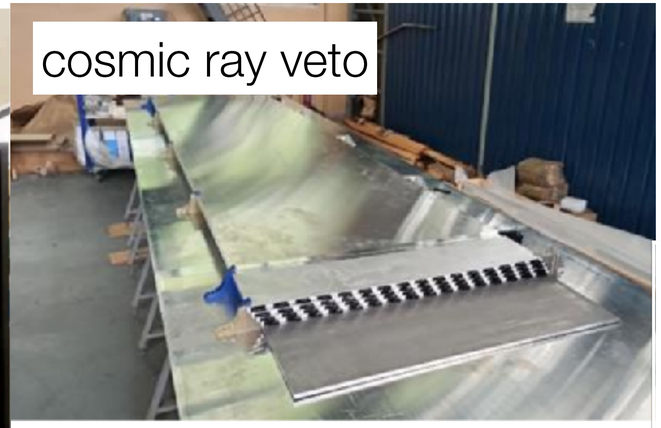
COMET Phase-I : Status











Timeline

- Phase-α in 2023 (finish last week!)
- Phase-I engineering run in 2024/2025
- Phase-I physics run start from 2024/2025
- Phase-II follows

Summary

- Muon CLFV processes provide a unique discovery potential for physics beyond the Standard Model.

- The muon CLFV programs, MEG II, Mu3e, Mu2e and COMET, are expecting significant experimental progress in coming years.

Thank you for your attention!

Thanks for Angela Papa and Andre Sheoning.